

(19) World Intellectual Property Organization
International Bureau(43) International Publication Date
26 September 2002 (26.09.2002)

PCT

(10) International Publication Number
WO 02/076028 A1

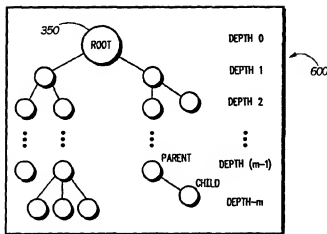
- (51) International Patent Classification: H04L 12/28 (74) Agents: FULLER, Andrew, S. et al.; 8000 West Sunrise Blvd., Room 1610, Fort Lauderdale, FL 33322 (US).
- (21) International Application Number: PCT/US02/07217
- (22) International Filing Date: 7 February 2002 (07.02.2002)
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data:
09/803,259 9 March 2001 (09.03.2001) US
- (71) Applicant: MOTOROLA, INC. [US/US]; 1303 East Algonquin Road, Schaumburg, IL 60196 (US).
- (72) Inventors: LEE, Chung-Chieh: 1715 Brookside Lane, Long Grove, IL 60047 (US). HESTER, Lance, E.: 2508 Coach House Way, Apt. 1D, Frederick, MD 21702 (US). O'DEA, Robert, J.: 2554 N.E. 26th Avenue, Fort Lauderdale, FL 33305 (US). CHEN, Priscilla; 7661 N.W. 42nd Place, #274, Sunrise, FL 33351 (US). ALLEN, Vernon, A.: 11847 N.W. 39th Street, Sunrise, FL 33323 (US). BOURGEOIS, Monique, J.: 1555 N.W. 91st Avenue, Coral Springs, FL 33071 (US).
- (81) Designated States (national): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LV, LU, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, UZ, VN, YU, ZA, ZM, ZW.
- (84) Designated States (regional): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— with international search report

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: A PROTOCOL FOR A SELF-ORGANIZING NETWORK USING A LOGICAL SPANNING TREE BACKBONE



(57) Abstract: A network protocol for low-cost, low-power device coupled to a self-organizing wireless network using a spanning tree backbone architecture is described. In this protocol, physical and logical network construction and maintenance operations, which supports efficient data routing in the network, are performed. The construction phase (991) in conjunction with the maintenance phase (905) insures the self-organizing capability of the network. At the same time, the maintenance (905) operations provide a self-healing mechanism (920) so that the network can recover from node failures and a self-updating mechanism so that the network can expand as more nodes enter the system. Also, the logical backbone hierarchy will facilitate multi-hop communication. The construction of a logical layered spanning tree backbone architecture from an underlying physical topology allows

seamless data communication routing between all nodes in the network.

WO 02/076028 A1

**A PROTOCOL FOR A SELF-ORGANIZING NETWORK USING A LOGICAL
SPANNING TREE BACKBONE**

5

CROSS REFERENCE TO RELATED APPLICATION

This application is related to the applications entitled "System for Spread Spectrum Communication" (Docket No. CM003551J), "A Multiple Access Protocol and
10 Structure for Communication Devices in an Asynchronous Network" (Docket No. 3526J) and "System for Code Division Multi-Access Communication" (Docket No. CM03333J), all filed on the same date as the present invention.

15

FIELD OF THE INVENTION

The present invention relates generally to wireless communication networks and more specifically to the use of a network protocol in wireless communication networks.

20

BACKGROUND OF THE INVENTION

Wireless communication networks often contain a great number of devices that can be randomly located throughout an indoor and/or outdoor communication environment. An
25 important issue is how to organize these communication devices physically and logically so that efficient inter-device communication is possible, and so that the resulting network is robust, scalable, and adaptable to changes in network topology. A primary wireless
30 networking technology currently in use is cellular telephony technology. This technology has weaknesses in the indoor environment, as well as in applications in which devices can be more efficiently connected to each other by communicating directly (i.e. the devices are in
35 close proximity of each other).

Technologies that currently address these cases are wireless Personal Area Networks (PAN) and wireless home networking products. In the former, devices are organized

into small networks designed to supplement current wide area networks such as cellular telephony. The networks allow a small number of devices to exchange data, and perform functions without the need for cable. Wireless home networking allows devices within a home to communicate with a central controller, normally a home computer or a cable set-top box. All devices in the network communicate directly with the central controller and not with each other. These networks are appropriate for their desired applications, but do not address the interconnection of multiple small low-cost and low-power wireless communication devices that may be scattered randomly throughout an indoor environment. These devices may be applied to remote sensing or control functions, signal processing, or communication functions. These devices require networks that are more scalable, robust to device failures, and employ efficient power conserving protocols.

In light of the foregoing, there is a need in the art for a network protocol for a self-organizing wireless network that provides physical and logical network construction, network routing, and network maintenance while addressing the issues associated with building a network around low-cost, low-power devices.

25

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the invention are set forth in the claims. The invention itself, however, as well as a preferred mode of use, and further objects and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

FIG. 1 shows a wireless communication network, according to the present invention.

FIG. 2 shows an internal block diagram of a representative wireless communication device, according to the present invention.

FIG. 3 shows the relationship between a node and it's neighbors in the wireless communication network, according to the present invention.

FIG. 4 is a flowchart of the network expansion process, according to the present invention.

FIG. 5 shows a new node X hello message, according to the present invention.

FIG. 6 shows the new node receiving Y reply messages, according to the present invention.

FIG. 7 shows the new node sending Z confirmation messages, according to the present invention.

FIG. 8 illustrates the spanning tree structure of a wireless communication network, according to the present invention.

FIG. 9 is a flowchart showing the construction of the logical network, according to the present invention.

- 5 **FIG. 10** shows the response of a node to an X hello message, according to the present invention.

FIG. 11 is a flowchart for the response of a node to a Y reply message, according to the present invention.

10

FIG. 12 is a flowchart for the response of a node to a Z confirm message, according to the present invention.

- 15 **FIG. 13** is a flowchart illustrating the node recovery process, according to the present invention.

FIG. 14 is a flowchart illustrating the process a node goes through when it has not received a message for a long period of time, according to the present invention.

20

FIG. 15 shows the format of the X Hello, Y Reply, Z confirm, Z broadcast, and W update message, according to the present invention.

- 25 **FIG. 16** shows an example of routing a message upstream when the destination is not on the direct path to the root node, according to the present invention.

- 30 **FIG. 17** shows an example of routing a message upstream when the destination is on the direct path to the root node, according to the present invention.

- 35 **FIG. 18** shows how the root node uses message broadcasting to route a source message to a destination, according to the present invention.

DESCRIPTION OF THE INVENTION

While this invention is susceptible of embodiment in many different forms, there is shown in the drawings and
15 will herein be described in detail specific embodiments, with the understanding that the present disclosure is to be considered as an example of the principles of the invention and not intended to limit the invention to the specific embodiments shown and described. In the
10 description below, like reference numerals are used to describe the same, similar or corresponding parts in the several views of the drawing.

The present invention discloses a method and structure for low-cost, low-power devices coupled to a
15 self-organizing wireless network using a spanning tree backbone architecture. The method and structure of the present invention may be described by examining the network protocol in terms of network construction, network routing protocols and network maintenance. The low-cost,
20 low power devices are typically fixed, wireless communication devices. Note that wireless technology includes the use of optical and microwave communication techniques. Also, the self-organizing wireless network may contain mobile as well as fixed nodes, although a
25 mobile node added to the network must move slowly enough so that the process of joining the network can be completed.

Referring to FIG. 1, a wireless network 100 is shown
30 in which n nodes are distributed throughout network 100. An additional node $N(n+1)$ 110 to be added to network 100 in accordance with the invention is also shown. Each node $N(1)$, $N(2)$, ..., $N(n)$ of network 100 contains functionality sufficient to allow the node to send messages, receive
35 messages, route data packets between nodes, facilitate multi-hop communications, store routing information, store neighboring node information, and supply an audio/visual

indicator to a user of the network. Additional functionality may be incorporated into each node without departing from the spirit and scope of the invention.

Referring to **FIG. 2**, a block flow diagram of the internal operation of a node 200 of the nodes $N(1), N(2), \dots, N(n)$ contained in network 100 is shown. Node 200 could be any node of the N nodes contained in network 100. Incoming messages 210 are first received by message receiver 230, which then prepares the incoming messages 210 for processing by message processor 240. Message processor 240 interacts with storage block 270, audio/visual indicator 260, and message router 250 in order to correctly process incoming messages 210. Node 200 also contains message transmission 280 capability that allows node 200 to prepare outgoing messages 220 created by either message router 250 or message processor 240. The outgoing messages 220 could include status messages, routed data messages, messages to nodes within communication range of node 200, or any similar type of message traffic. Referring again to **FIG. 2**, note that while the functionality shown has been placed in separate blocks, the internal blocks shown could be further separated or combined in functionality without departing from the spirit and scope of the present invention.

Referring now to **FIG. 3**, a representation 300 of that part of network 100 coupled to a typical node $N(k)$ 310 is shown. Note that the k index of node $N(k)$ indicates that node $N(k)$ 310 could be any node of the nodes $N(1), N(2), \dots, N(n)$ contained in network 100. Node $N(k)$ 310 contains, in addition to the functionality described in **FIG. 2**, a range list $RL(k)$ 320, and a routing table $RT(k)$ 330. $RT(k)$ 330 and $RL(k)$ 320 are stored in the memory of node $N(k)$ 310, shown as storage 270 in **FIG. 2**. Range list $RL(k)$ 320 contains information about nodes $N(b1(k)), N(b2(k)), \dots, N(bb(k))$ 360 that are neighbors of node $N(k)$ 310. This information may include neighbor ID, neighbor load information, neighbor children information, the

parent node of each neighbor, and the depth of each neighbor from a root node of the network. The neighbor ID may be a logical address or a physical address. A neighbor is any node of the n nodes contained in network 100 that is within direct communication range of node $N(k)$ 310. As indicated in FIG. 3, root node $N(R)$ 350 may also be a neighbor of node $N(k)$ 310, provided it is within communication range of node $N(k)$ 310. Routing table $RT(k)$ 330 contains information that enables node $N(k)$ 310 to assist in the routing of a data packet from a source node $N(s)$ to a destination node $N(d)$.

Each node $N(1)$, $N(2)$, ..., $N(n)$ in network 100 contains a parent node, with the exception of root node $N(R)$ 350. There is one root node $N(R)$ 350 in network 100, and every node $N(1)$, $N(2)$, ..., $N(n)$ is a descendant of root node $N(R)$ 350. The parent of node $N(k)$ 310 is designated $N(P(k))$ 370. Node $N(k)$ 310 may also have one or more children nodes $N(c1(k))$, $N(c2(k))$, ..., $N(cc(k))$ 380 attached to node $N(k)$ 310. Each node $N(cx(k))$ of $N(c1(k))$, $N(c2(k))$, ..., $N(cc(k))$ is a child node of node $N(k)$ 310 if data routed from node $N(cx(k))$ must pass through node $N(k)$ 310 in order to reach root node $N(R)$ 350. A new node $N(n+1)$ 110 that has not yet joined network 100 may also interact with node $N(k)$ 310 in the process of joining network 100.

Construction of network 100 begins with a physical topology construction process. Referring to FIGs. 4, 5, 6, and 7, the physical topology construction process for establishing communication between a new node $N(n+1)$ to be added to the network and the existing, fixed nodes of the network $N(1)$, $N(2)$, ..., $N(n)$ is illustrated. During physical topology construction, fixed wireless nodes $N(1)$, $N(2)$, ..., $N(n)$ are deployed into network 100. A user adding node $N(n+1)$ 110 to expand network 100 (block 450) is responsible for positioning node $N(n+1)$ 110 so that it is within communication range of at least one other node connected to network 100. Node $N(n+1)$ 110 has an audio/visual display that indicates when node 110 is able

to communicate with at least one of the fixed wireless nodes $N(1)$, $N(2)$, ..., $N(n)$ already in the network. Referring now to **FIG. 5**, representative of block 453 of **FIG. 4**, network 100 with n nodes is shown as well as new node $N(n+1)$ 110. Node $N(n+1)$ 110 broadcasts X hello message 410 to each node of fixed wireless nodes $N(1)$, $N(2)$, ..., $N(n)$ of network 100 that is within communication range of node $N(n+1)$ 110. Referring now to **FIG. 6** and block 456 of **FIG. 4**, one or more nodes $N(j)$, ..., $N(w)$ 430 of the fixed wireless nodes $N(1)$, $N(2)$, ..., $N(n)$ reply to X hello message 410 with a Y reply message 420 informing node $N(n+1)$ 110 that the one or more nodes $N(j)$, ..., $N(w)$ 430 are within communication range of node $N(n+1)$ 110. If node $N(n+1)$ 110 receives Y reply message 420 from any of the one or more nodes $N(j)$, ..., $N(w)$ 430, then node $N(n+1)$ 110 adds the sending node of Y reply message 420 to the range list $RL(n+1)$ of node $N(n+1)$ 110 (block 459). Additional information can be added to the range list including, loading information, and depth to root. Y reply messages 420 are received by new node $N(n+1)$ 110 for a period of time (block 462). If no Y reply message 420 is received by node $N(n+1)$ 110 after a certain time (block 462), then the range list of node $N(n+1)$ 110 will be empty (block 465), and an indicator 260 will alert the user. Node $N(n+1)$ 110 must then be physically moved to a new location, corresponding to block 477 and the network topology construction process starts again with network expansion (block 450). Assuming at least one Y message was received (block 465), the parent node $N(P(n+1))$ of node $N(n+1)$ 110 is selected (block 468). Parent node $N(P(n+1))$ is determined from the minimum depth $m(n+1)$ from the root node of all nodes in the range list $RL(n+1)$ 320 and the smallest load of the nodes having minimum depth $m(n+1)$. Note that other selection criteria using specific loading information could be used without departing from the spirit and scope of the invention. The depth of node $N(n+1)$ 110 is set to be the minimum depth $m(n+1)$ plus one

(block 471). Referring now to **FIG. 7** and block 474 of **FIG. 4**, node $N(n+1)$ 110 replies to each of the one or more nodes $N(j), \dots, N(w)$ 430 that sent Y reply message 420 with a broadcast Z confirmation message 440 confirming that the nodes are within range of each other (block 474). A broadcast Z message sends a confirmation to the one or more nodes that sent reply messages. A node may also send a Z message that is sent to only one other node, but with the same purpose. Broadcast Z confirm message 440 includes the new nodes address. If logical addressing is used, the new node address is a logical address containing the node $N(n+1)$ 110 depth information and the parent's identity. After sending the broadcast Z confirmation message 440, node $N(n+1)$ enters a maintenance mode (block 490), during which normal network operation occurs.

In addition to the network expansion process of network 100 illustrated in **FIG. 4**, the logical construction process of network 100 is performed, which is derived from the physical construction process. The logical construction process occurs when node $N(n+1)$ 110, which has just completed physical construction process 400, is added to the logical spanning tree architecture of network 100. The logical construction derived using the logical construction process is a spanning tree derived from the underlying physical topology. Referring to **FIG. 8**, a representative spanning tree architecture is shown. The first node $N(1)$ that starts the physical topology and the logical topology is designated Root node 350. Each additional node is added as a child of the Root node 350. Various addressing schemes may be used to uniquely locate a node within the spanning tree architecture. If logical addressing is used, then each node receives a unique address that includes information about the nodes neighbors and children within the network 100. Other types of addressing, such as fixed addressing do not contain any indication of the location of the node within network 100.

Note that if logical addressing is used, the logical address assignment can be done with the traverse tree or the non-traverse tree method, although the described procedure above suggests a traverse tree method. In the traverse tree method, the size of the network is determined a priori (how many layers, how many nodes in a layer), and logical addresses are then assigned to the nodes as they enter the network. In the non-traverse tree method, the physical topology of all the nodes in the network is decided first and logical addresses are then assigned to them according to their relative physical topology. A non-traverse tree has to wait until all nodes are entered into the network and the physical topology is constructed first; however it does not waste logical addresses like the traverse tree method.

Referring now to **FIG. 9**, a flowchart illustrating the network maintenance mode 900 is shown. The maintenance mode 900 occurs during normal network operation when representative node N(k) 310 has already entered the network 100 and completed network expansion 450. The maintenance mode 900 begins at block 905 when node N(k) 310 checks to see if any messages have been received (block 910). If no messages have been received for a specified time T (block 945), then the time out mode (block 947) begins. Otherwise the maintenance mode 900 continues to check for and process any messages. Once an X, Y, broadcast Z, Z or W message has been received (block 910), the appropriate processing function is called. If an X hello message is received (block 935), then the X message process begins (block 937). If a Y reply message is received (block 950), then the Y reply message process begins (block 953). If a Z confirm or broadcast Z confirm message is received (block 960), then the Z confirm message process begins (block 962). The X, Y, broadcast Z, and Z messages have been introduced in the discussion of **FIG. 4**. The W update message is received periodically from neighbor nodes to update or confirm their status that

may or may not affect other nodes in the network 100. If the message received is not an X, Y, broadcast Z, Z, or W message, then the maintenance cycle continues from block 905 and the unidentified message is not processed.

5

If a W update message is received (block 915), then node N(k) 310 compares the senders ID to the contents of the range list of node N(k) 310 (block 920). If the sending node is a new neighbor (block 925), the node N(k) 310
10 sends out a Y reply message (block 930), and re-enters the maintenance mode 900 (block 905). If the sending node is not a new neighbor, and if the range list entry for that neighbor has not changed (block 940), node N(k) 310 again re-enters the maintenance mode (block 905). If the range
15 list has changed (block 940), a new minimum depth $m(k)$ is computed (block 955), and the new minimum depth is compared to the old minimum depth (block 965). If they are equal (block 965), then node N(k) 310 re-enters maintenance since the parent node does need to be changed.
20 If the new $m(k)$ is greater than the old $m(k)$, then the node recovery mode (block 971) begins since the node N(k) 310 is now further from the Root node 350 than before.

Otherwise, the new $m(k)$ is less than the old $m(k)$ (block
25 970), and, if logical addressing is not used (block 982), the new parent is chosen to be the sending node (block 975). The depth of node N(k) 310 is set to be one plus $m(k)$ (block 977), and a Z confirm message is sent to the new parent (block 980). Then a W update message is
30 broadcast (block 985), and the node N(k) 310 re-enters the maintenance mode (block 905).

If the new $m(k)$ is less than the old $m(k)$ (block 970), and logical addressing is used (block 982), then the old
35 parent information is stored (block 972), and the new parent is chosen to be the sending node (block 973). The depth of node N(k) 310 is set to be one plus $m(k)$ (block

976), and a Z confirm message is sent to the new parent (block 979). A time out period is enforced (block 987), and node N(k) 310 checks if a Y reply message has been received from the newly selected parent (block 973). If
5 no Y message is received before the time out, the original parent, ID and depth, $d(k)$, are restored (block 995), and the node N(k) 310 re-enters the maintenance mode (block 905). If a Y message was received from the new parent prior to time out (block 987), node N(k) 310 checks the
10 contents of the message to see if the destination address is the same one the receiving node N(k) 310 planned to use. If not, the receiving node N(k) 310 updates its own logical address to reflect the new address assigned to it by the parent (block 991), sends a Z confirm message to
15 the new parent (block 993), a W update message (block 985), and the node N(k) 310 re-enters the maintenance mode (block 905).

One of the messages received during maintenance mode 900 is the X hello message. Referring to **FIG. 10**,
20 receiving an X message during the maintenance mode 900 causes node N(k) 310 to send a Y message (block 1010), and wait for the expected broadcast Z message (block 1020). If a broadcast Z message has not been received by a specified time (block 1040), then the node takes no action
25 and re-enters the maintenance mode 900 (block 905). If a broadcast Z message is received (block 1020), then the node that sent the X message is added to the range list of node N(k) 310, and the child list is updated if necessary (block 1030). Node N(k) 310 then re-enters the
30 maintenance mode 900 (block 905).

Referring now to **FIG. 11**, the response of a node N(k) 310 in network 100 to a Y reply message received during maintenance 900 is shown. After receiving a Y message (block 953), node N(k) 310 adds the sending node to the
35 range list of the receiving node (block 1105). If the depth of the sender is greater than or equal to the smallest depth of all the other nodes in the receiving

node's range list (block 1110), then the receiving node does not need a new parent (block 1140). Send a Z message to the sending node (block 1140) and go to maintenance mode 900.

- 5 If the sending node is closer to the root than the current parent (block 1110), and logical addressing is not used (block 1115), set the new parent to be the sender (block 1120), and update the new depth of node $N(k)$ 310 to be the minimum depth plus 1 (block 1125). Next, send a Z
10 message to the new parent (block 1130), broadcast a new W update message (block 1135), and return to maintenance mode 900.

- If logical addressing is used (block 1115), store the current parent's information (block 1145), and assign the
15 sender to be the new parent (block 1150). Update the receiving node's depth and logical address accordingly (block 1155). Now a handshaking sequence must be executed to make sure another node has not already claimed the logical address chosen by the receiving node. The
20 receiving node sends a Z message (block 1160), containing its proposed logical address, to the sender (the new parent). The receiving node must wait (block 1170) for a Y response from the new parent. If no response is received (block 1165), the receiving node cannot use the new
25 parent. It must restore its original parent information (block 1185), and return to maintenance (block 905).

- If a Y message is received from the parent (block 1165), the receiving node must use whatever logical address the parent sends for it in the Y message. The
30 receiving node updates its logical address if necessary (block 1175), and sends a Z message to the new parent with the new agreed upon logical address (block 1175). The receiving node broadcasts a W message with its new information (block 1135) and goes to maintenance (block
35 905).

Referring now to **FIG. 12**, a Z message is received during maintenance (block 962). If the receiving node was

not chosen as the sender's parent (block 1210), then update the node sending the Z message in the range list of the receiver (block 1240) and return to maintenance (block 905). If the receiving node was chosen as the sender's parent (block 1210), and a broadcast Z message was received (block 1220), update the node sending the Z message in the range list of the receiver (block 1240) and return to maintenance (block 905). Also, if the Z message is not a broadcast Z (block 1220), and logical addressing is not used, then update the node sending the Z message in the range list of the receiver (block 1240) and return to maintenance (block 905).

If the received message was a regular Z message (block 1220), and logical addressing is used (block 1230), make sure the new child node has chosen a valid logical address (block 1250). If the address is valid, send a Y message to the child using the same address (block 1260). If some other node has already taken the address, choose a new logical address for the new child and include it in a Y message (block 1280). In either case of block 1250, wait for a Z message from the child as confirmation (block 1270). If no Z message is received within a specified time out period (block 1290), do not update the sending node's information in the range list. Return to maintenance (block 905).

If a Z message is received (block 1270), update the receiving node's range list to include the sender's information (block 1240), and return to maintenance (block 905).

Referring now to **FIG. 13**, a flowchart illustrating how a node recovers from a change in network topology is shown. Upon entering recovery (block 971), compare the new minimum depth value, m_i , with the node's own depth (block 1333). Remember that, under normal circumstances, the node's depth should be one greater than the minimum depth. That is, the parent node should be closer to the root than the child node.

If the minimum depth is less than the node's depth, find a new parent based on minimum depth from the root, and use the loading information as a tiebreaker if necessary (block 1338). Set the new parent (block 1342), and send a Z message to the prospective parent (block 1344). If logical addressing is not used, simply broadcast a W update message informing neighbors of the new parent (block 1348), and return to maintenance (block 905). If logical addressing is used, wait for a Y message from the prospective parent (block 1352).

If the Y message is received, make sure that the child node uses the logical address sent by the parent in the contents of the Y message (block 1356). It is important that only one node uses that address. Send the Z message with the agreed upon logical address (block 1358), and broadcast a W message with the child's new information (block 1348). Return to maintenance (block 905).

If no Y message is received from the prospective parent (block 1352) after a specified time out period (block 1354), do not use that node as a parent, because there was no agreement. Instead, delete the parent from the range list (block 1360), and check to see if range list is empty. If the range list is not empty, find a new parent based upon minimum depth and load (block 1340), and return to block 1342. This process continues until an appropriate parent is found or the range list is empty (block 135). If the range list is empty (block 135), set the parent to nil, and set the minimum depth, m_i , and the node's own depth, d_i , to infinity (block 1362). Send a W message with this new information (block 1364). Wait for W or Y messages to be received from other nodes in the network (block 1368). For every W or Y message received, add the sending node to the range list (block 1374). Repeat block 1368 until a time out is reached (block 1355).

After the timeout period (block 1366), determine minimum depth again (block 137). If it is still infinity

(block 1372), the node is disconnected since no W or Y messages were received. A user may turn on audio/visual indicator 260 (block 1376), and wait for a period of time (block 1378) before going to network expansion mode (block 450) to try to reconnect. If the minimum depth is not infinity, go to block 1336 to choose a new parent.

Referring now to **FIG. 14**, the flowchart for the time out mode is shown. The time out mode begins (block 947) when no messages are waiting to be processed and it has been more than a specified period of time since the last time out occurred. Any entries in the range list that correspond to nodes that have not been heard from in a specified amount of time are deleted (block 1433 and block 1436)). That is, the receiving node has not gotten a W message from a neighbor node within a specified time. If the range list is empty (block 1438), the node is no longer part of the network. Turn on audio/visual indicator 260 (block 1440), and wait for a period of time (1442) before going to network expansion (block 45).

If the range list is not empty but the parent has been deleted, determine a new minimum depth (block 1446), and go to recovery (block 971).

If the range list is not empty, the parent is still in the range list (block 1444), and logical addressing is not used (block 1448), send out a broadcast W update message (block 1450) and return to maintenance (block 905).

If logical addressing is used (block 1448), update the child node logical address list, if necessary (block 1452). If the child node logical address list is up to date, go to block 1450. Otherwise, take the child node at the bottom of the list, which is the largest value in the logical address field, and give it the logical address corresponding to the vacancy with the smallest value in the logical address field (block 1454).

Each time an address is changed, the parent must send out a Y message letting the child know of its new address

(block 1456). If a Z message is received from the child (block 1458), change the child's address in the range list (block 1462). If a Z message is not received (block 1458) within a specified time out period (block 1460), do not
5 change the child's address in the range list, because the child has not acknowledged the change. For each vacancy in the child list, the reassignment process starting at block 1454 is repeated (block 1464). When there is a vacancy and all children have been tried (block 1464), send a W
10 message (block 1450). The flow next goes to maintenance (block 905).

Referring now to **FIG. 15**, the format of the X, Y, Z, Broadcast Z, and W messages are shown. Each message contains network topology information that allows nodes
15 within the network to determine a location within the spanning tree architecture that is as close as possible to the root node while still accounting for parent, child and loading information.

The X hello message 410 contains the following
20 fields: Bit Sync (1530), Frame Sync (1535), Message Type (1540), Source Node ID (1545), an optional field (1550), and a CRC field (1552).

The Y reply message 420 contains the following
25 fields: Bit Sync (1554), Frame Sync (1556), Message Type (1558), Source Address (1560), Destination Address (1562), Destination Node ID (1564), a Load Field (1566), an optional field (1568), and a CRC field (1570).

The Z reply message 1520 contains the following
30 fields: Bit Sync (1572), Frame Sync (1574), Message Type (1576), Source Address (1578), Destination Address (1580), Source Node ID (1582), a Load Field (1584), an optional field (1586), and a CRC field (1588).

The Broadcast Z confirm message 440 contains the following fields: Bit Sync (1590), Frame Sync (1592),
35 Message Type (1594), Source Address (1596), a Load Field (1597), an optional field (1598), and a CRC field (1599).

The W update message 1525 contains the following fields: Bit Sync (1531), Frame Sync (1541), Message Type (1551), Source Address (1561), a Load Field (1571), an optional field (1581), and a CRC field (1591).

5 The Bit Sync and Frame Sync have the same definition for each message type, and allow each node to perform synchronization on incoming messages. This synchronization can occur at the frame level and at the bit level.

10 The Message Type is also the same for each message. The message type lets the receiving node know which type of message is coming in so that the receiving node will be able to understand the rest of the message.

15 Each message also contain an optional field, which is currently not used. Note that the size of this field varies between message types.

 The CRC field is also present in each message type. This field allows received packets to be checked for errors.

20 For the X hello message 410, the source node ID (1545) is randomly selected. Each node will have a random ID, which is necessary for the case when a Y message is sent to a new node (in response to an X message). Because a new node does not yet have an assigned logical address, 25 there must be some other node ID to identify for whom the Y message is intended.

 For the Y reply message 420, if the source address is the logical address of the sending node; if logical addressing is not used in the network, the source address 30 can just be a random ID. The destination address contains the proposed logical address of the receiving node. In other words, this will be the logical address of the receiving node if the sending node is chosen as the receiving node's parent. The destination node ID is the random node ID, as described for the X message, of the 35 receiving node. The Load field currently contains the number of neighbors that the sending node currently has in

its neighbor list. This can be used as a loading parameter in a future protocol version.

For the Z confirm message 1520, the source address is the same as for Y message. The destination address may
5 contain the logical address of the receiving node; again, if logical addressing is not used in the network, the destination address may be a random ID. The source node ID has the same definition as the source node ID in the X Hello message 410. The Load field currently contains the
10 number of children of the sending node and the number of neighbors of the sending node. This parameter can be used for load balancing.

For the broadcast Z confirm message 440, the source address is the same as for Y message. The Load field is
15 the same as for Z message.

For the W message 1525, the source address is the same as for Y message. The Load field is the same as for Z message.

Each fixed node of the fixed wireless nodes of the
20 network maintains a simple routing table containing the fixed node's range, the fixed node's depth, its parent, and the fixed node's load parameter. Shortest path routing is not performed by any fixed node of the fixed wireless nodes $N(1)$, $N(2)$, ..., $N(n)$. Mobile wireless nodes
25 may exist in the network 100, but fixed nodes perform message routing. Messages from a source node to a destination node within network 100 can travel through the network 100 from the source node to Root node $N(R)$ 350, then down to reach the destination node in several ways.
30 Referring now to **FIG. 16**, a spanning tree logical backbone hierarchy 1600 is shown in which source node 1610 and destination node 1620 are labeled. Note that destination node 1620 is not in the upstream path. A message 1630 from source node 1610 sent to destination node 1620 is
35 transferred from node to node so that each successive transfer brings the message one hop closer to Root node $N(R)$ 350. This node hopping continues until the message

reaches Root node N(R) 350. Referring now to routing protocol 1800 of **FIG. 18**, Root node N(R) 350 then broadcasts this message to each node of the fixed wireless nodes N(1), N(2), ..., N(n) in network 100. Alternatively, 5 Root node N(R) 350 can use source routing or multi-hop local broadcasting to transmit the message from Root node N(R) 350 to destination node 1810.

FIG. 17 illustrates a spanning tree logical backbone hierarchy 1700 in which source node 1710 and destination 10 node 1720 are in the upstream path. In **FIG. 17**, a message sent from source node 1710 to destination node 1720 is transferred from node to node so that each successive transfer brings the message one hop closer to Root node 350 N(R). Prior to reaching Root node 350 N(R), 15 destination node 1720 is reached. Since the message has arrived at destination node 1720, Root node 350 N(R) is not involved, and no broadcast message is required.

While the invention has been described in conjunction with specific embodiments, it is evident that many 20 alternatives, modifications, permutations and variations will become apparent to those of ordinary skill in the art in light of the foregoing description. Accordingly, it is intended that the present invention embrace all such alternatives, modifications and variations as fall within 25 the scope of the appended claims.

What is claimed is:

1. A method of expanding a logical topology representative of a network having a plurality of network nodes to include a node added to the network, comprising:
- identifying one or more neighboring nodes of the
 - 5 plurality of network nodes that are within communication range of the node;
 - obtaining network topology information of the one or more neighboring nodes;
 - from the network topology information of the one or
 - 10 more neighboring nodes identifying a neighboring node of the one or more neighboring nodes having a minimum depth from a root node of the network and assigning the neighboring node having the minimum depth from the root node as a parent node of the node; and
 - 15 the node transmitting a broadcast confirmation message that informs the one or more neighboring nodes of an identifier of the parent node and a depth of the node from the root node.
- 20 2. The method of claim 1, wherein identifying the one or more neighboring nodes within communication range of the node comprises:
- the node sending a hello message to the plurality of network nodes of the network;
 - 25 upon receiving the hello message, the one or more neighboring nodes transmitting one or more corresponding reply messages to the node;
 - in response to receiving the one or more reply messages sent by the one or more neighboring nodes, the
 - 30 node adding the one or more neighboring nodes to a range list of the node;

3. The method of claim 1, further comprising:
in response to receiving the broadcast confirmation message, the one or more neighboring nodes adding the node to one or more corresponding range lists of the one or more neighboring nodes.

4. The method of claim 1, wherein identifying the one or more neighboring nodes within communication range of the node comprises:

the node transmitting a hello message to the plurality of network nodes of the network;

after a time-out period, determining whether the one or more neighboring nodes have transmitted one or more corresponding reply messages to the node;

if the one or more neighboring nodes have transmitted the one or more corresponding reply messages, the node adding the one or more neighboring nodes to a range list of the node; and

if the one or more neighboring nodes have not transmitted the one or more corresponding reply messages, activating a disconnect indicator of the node.

5. The method of claim 4, further comprising after activating the disconnect indicator:

re-positioning the node within the network and re-transmitting the hello message to the plurality of network nodes of the network.

6. The method of claim 4, wherein if the hello message is not received by the one or more neighboring nodes, re-positioning the node within the network and re-transmitting the hello message.

7. The method of claim 1, wherein the network topology information comprises one or more of depth, loading, and identifier information.

8. The method of claim 1, wherein the depth of the node from the root node is one greater than the minimum depth of the parent node.

- 5 9. The method of claim 1, wherein if two or more of the neighboring nodes have the minimum depth from the root node, assigning a neighboring node of the two or more neighboring nodes having a least number of children nodes as the parent node of the node.

10

10. A method of maintaining a physical topology of a network, having a plurality of network nodes, and a logical topology representative of the physical topology, comprising:
- 5 a first network node receiving a first update message from a second network node of the plurality of network nodes within communication range of the first network node; and
 - 10 if the second network node is not in a range list of the first network node and therefore a new neighbor of the first network node, updating the range list of the first network node to include the second network node.
11. The method of claim 10, wherein updating the range list of the first network node to include the second network node comprises:
- the first network node transmitting a first reply message to the second network node;
 - 20 the second network node receiving the first reply message from the first network node and adding the first network node to the range list of the second network node;
 - the second network node transmitting a first confirmation message to the first network node containing
 - 25 network topology information about the second network node; and
 - the first network node receiving the first confirmation message from the second network node and adding the second network node to the range list of the
 - 30 first network node.
12. The method of claim 11, wherein in response to the second network node receiving the first reply message and prior to the second network node transmitting the first
- 35 confirmation message, further comprising:

determining if a depth of the first network node from the root node is less than a minimum depth of an existing parent node of the second network node;

if the depth of the first network node from the root node is less than the minimum depth of the existing parent node of the second network node, further comprising:

determining if logical addressing is used in the network;

if logical addressing is not used, further comprising:

assigning the first network node as a new parent node of the second network node;

the second network node transmitting a second confirmation message to the first network node; and

the second network node transmitting a second update message to the plurality of network nodes containing information about the new parent node of the second network node;

if logical addressing is used, further comprising:

storing a logical address and an identifier of an old parent node of the second network node;

assigning the first network node as the new parent node of the second network node;

the second network node transmitting a second confirmation message to the first network node;

if the second network node receives a second reply message from the first network node in response to the second confirmation message, comprising:

the second network node updating a logical address of the second network node;

the second network node transmitting a third confirmation message to the first network node; and

the second network node transmitting a second update message;

if the second network node does not receive the second reply message from the first network node in

response to the second confirmation message within a first time-out period, the second network node restoring the old parent node as parent of the second network node;

- 5 if the depth of the first network node from the root node is not less than the minimum depth of the parent node of the second network node, the second network node transmitting the confirmation message.

13. A method of maintaining a physical topology of a network, having a plurality of network nodes, and a logical topology representative of the physical topology, comprising:

- 5 a first network node receiving a first update message from a second network node of the plurality of network nodes within communication range of the first network node; and
 - 10 if the second network node is contained within the range list of the first network node, comprising:
 - 15 determining whether information contained in the first update message about the second network node matches information contained in the range list of the first network node about the second network node;
 - 20 if the information contained in the first update message about the second network node does not match information contained in the range list of the first network node about the second network node, using the information contained in the first update message about the second network node and the range list of the first network node to determine if an old parent node of the first network node provides the first network node with a minimum depth from a root node of the network and updating the first network node to have a new parent node if the
 - 25 old parent node does not provide the minimum depth from the root node.

- 14. The method of claim 13, wherein if the information contained in the first update message about the second network node does not match information contained in the range list of the first network node about the second network node, further comprising:

- 30 using the information contained in the first update message about the second network node and information contained in the range list of the first network node to determine a new minimum distance of the plurality of network nodes from the root node;

if the new minimum distance is less than an old minimum distance of the plurality of network nodes from the root node, further comprising:

assigning the second network node as a new parent node of the first network node;

the first network node transmitting a first confirmation message to the second network node containing a new depth of the first network node from the root node with the second network node as the new parent node;

determining if logical addressing is used in the network;

if logical addressing is not used, further comprising:

the first network node transmitting a second update message to the plurality of network nodes containing information about the new parent node of the first network node;

if logical addressing is used, further comprising:

determining whether the first network node has received a first reply message from the second network node;

if the first network node has not received the first reply message from the second network node, restoring a logical address and an identifier of the old parent node to the range list of the first network node; and

if the first network node has received the first reply message from the second network node, the first network node updating a logical address of the first network node, transmitting a second confirmation message to the second network node;

if the new minimum distance is greater than the old minimum distance from the root node, entering a recovery mode to assign the new parent node of the first network node.

15. The method of claim 14, wherein the recovery mode further comprises:
- determining whether the new minimum distance of the plurality of network nodes from the root node is less than a depth of the first network node from the root node;
 - if the new minimum distance from the root node is less than a depth of the first network node from the root node, further comprising:
 - identifying a network node of the plurality of network nodes having the new minimum distance;
 - assigning the network node as the new parent node of the first network node;
 - the first network node transmitting a first confirmation message to the new parent node;
 - 15 determining whether the network uses logical addressing;
 - if the network uses logical addressing, further comprising:
 - if the first network node has received a first reply message from the new parent node in response to the first confirmation message, the first network node updating a logical address of the first network node and transmitting a second confirmation message to the new parent node;
 - 20 if the first network node has not received the first reply message from the new parent node, further comprising:
 - deleting the new parent node from the range list of the first network node.
 - 30 determining whether the range list of the first network node is empty;
 - if the range list of the first network node is not empty, determining a second new parent node for the first network node based upon the minimum depth of the plurality of network nodes;
 - 35

the first network node transmitting a second update message containing information about the new parent node of the first network node.

- 5 if the new minimum distance from the root node is not less than a depth of the first network node from the root node or if the range list of the first network node is empty, further comprising:

10 setting the new parent node of the first network node to nil, the minimum depth of the plurality of network nodes to infinity, and the depth of the first network node from the root node to infinity;

15 the first network node transmitting a second update message containing information about the settings of the new parent node, the minimum depth, and the depth of the first network node;

20 if a third update message or a third reply message is received by the first network node from a third network node during a third time-out period, the first network node updating the range list of the first network node to include the third network node;

 determining a new minimum depth of the plurality of network nodes;

25 if the new minimum depth is equal to infinity, activating a disconnect indicator of the first network node; and

 if the new minimum depth is not equal to infinity, determining the new parent of the first network node.

- 30 16. The method of claim 15, wherein if the new minimum distance from the root node is less than the depth of the first network node, identifying the network node having the new minimum distance and having a minimum load value of the plurality of network nodes.

35

17. The method of claim 15, wherein deleting the new parent node from the range list of the first network node occurs after a second time-out period.

18. A method of maintaining a physical topology of a network, having a plurality of network nodes, and a logical topology representative of the physical topology,
- 5 comprising:
- a first network node receiving a first update message from a second network node of the plurality of network nodes within communication range of the first network node;
 - 10 if the second network node is not in a range list of the first network node and therefore a new neighbor of the first network node, updating the range list of the first network node to include the second network node; and
 - if the second network node is contained within the
 - 15 range list of the first network node, comprising:
 - determining whether information contained in the first update message about the second network node matches information contained in the range list of the first network node about the second network node;
 - 20 if the information contained in the first update message about the second network node does not match information contained in the range list of the first network node about the second network node, using the information contained in the first update message about
 - 25 the second network node and the range list of the first network node to determine if an old parent node of the first network node provides the first network node with a minimum depth from a root node of the network and updating the first network node to have a new parent node if the
 - 30 old parent node does not provide the minimum depth from the root node.

19. A method of maintaining a physical topology of a network, having a plurality of network nodes, and a logical topology representative of the physical topology,
5 comprising:

a first network node receiving a hello message from a second network node of the plurality of network nodes within communication range of the first network node, the hello message containing network topology information
10 about the second network node; and

in response to receiving the hello message, the first network node transmitting a reply message containing network topology information about the first network node; and

15 the first network node updating a range list of the first network node to include the network topology information about the second network node and the second network node updating a range list of the second network node to include the network topology information about the
20 first network node.

20. The method of claim 19, further comprising:

In response to receiving the reply message from the first network node, the second network node transmitting a
25 broadcast confirmation message.

21. The method of claim 20, wherein upon receiving the broadcast confirmation message, the first network node updating a child list of the range list of the first
30 network node.

22. A method of maintaining a physical topology of a network, having a plurality of network nodes, and a logical topology representative of the physical topology, comprising:
- 5 a first network node of the plurality of network nodes receiving a reply message from a second network node of the plurality of network nodes that is within communication range of the first network node; and
 - 10 the first network node adding network topology information of the second network node to a range list of the first network node.
23. The method of claim 22, further comprising:
- 15 if a depth of the first network node from a root node of the network is greater than or equal to a minimum depth of the plurality of network nodes from the root node, the first network node transmitting a confirmation message to inform the second network node;
 - 20 if the depth of the first network node from the root node of the network is less than the minimum depth of the plurality of network nodes from the root node, further comprising:
 - if the network does not use logical addressing,
 - 25 comprising:
 - assigning the second network node as a new parent node of the first network node;
 - the first network node transmitting a second confirmation message to the second network node; and
 - 30 the first network node transmitting a second update message to the plurality of network nodes containing information about the new parent node of the first network node;
 - if the network does use logical addressing, further
 - 35 comprising:
 - storing a logical address and an identifier of an old parent node of the first network node;

35

assigning the second network node as the new parent node of the first network node;
the first network node transmitting a second confirmation message to the second network node;
5 if the first network node receives a second reply message from the second network node in response to the second confirmation message, comprising:
the first network node updating a logical address of the first network node;
10 the first network node transmitting a third confirmation message to the second network node; and
the first network node transmitting a second update message;
if the first network node does not receive the
15 second reply message from the second network node in response to the second confirmation message within a first time-out period, the first network node restoring the old parent node as parent of the first network node and transmitting a second update message.
20

24. A method of maintaining a physical topology of a network, having a plurality of network nodes, and a logical topology representative of the physical topology, comprising:

5 a first network node of the plurality of network nodes receiving a confirmation message from a second network node of the plurality of network nodes that is within communication range of the first network node; and
10 the first network node updating a range list of the first network node to include network topology information about the second network node contained in the confirmation message.

15 25. The method of claim 24, wherein prior to the first network node updating the range list of the first network node to include network topology information about the second network node contained in the confirmation message, further comprising:

20 if the first network node determines from the confirmation message that the first network node has been picked as a parent node of the second network node, verifying that the second network node has selected a valid logical address of the second network node.

25 26. The method of claim 25, wherein if the second network node has not selected a valid logical address, the first network node choosing a new logical address of the second network node; and

30 the first network node transmitting a reply message to the second network node containing the new logical address of the second network node.

27. The method of claim 25, further comprising:

the first network node updating the range list of the first network node to include the new logical address of the second network node after receiving a second confirmation message from the second network node.

28. The method of claim 25, further comprising:

the second network node updating a range list of the second network node to include the new logical address transmitted from the first network node.

29. The method of claim 24, wherein prior to the first network node updating the range list of the first network node to include network topology information about the second network node contained in the confirmation message, further comprising:

if the first network node determines from the confirmation message that the first network node has been picked as a parent node of the second network node and that the confirmation message is not a broadcast confirmation message, verifying that the second network node has selected a valid logical address of the second network node;

if the second network node has not selected a valid logical address, the first network node choosing a new logical address of the second network node;

the first network node transmitting a reply message to the second network node containing the new logical address of the second network node.

30. A method of maintaining a physical topology of a network, having a plurality of network nodes, and a logical topology representative of the physical topology, comprising:

5 examining a range list of a first network node of the plurality of network nodes, having one or more entries that correspond to one or more network nodes of the plurality of network nodes, to determine which of the one
10 or more network nodes that the network node has not heard from for a period of time;

 deleting from the range list each network node of the one or more network nodes that the network node has not heard from for the period of time to generate an updated
15 range list of the first network node.

31. The method of claim 30, further comprising:

 transmitting an update message containing information about the updated range list of the first network node.
20

32. The method of claim 30, further comprising:

 if a parent node of the first network node was deleted from the range list, selecting a new parent node of the first network node from the plurality of network
25 nodes having a minimum depth to a root node of the network.

33. The method of claim 32, wherein the new parent node of the first network node has the minimum depth to the
30 root node and a minimum load value of the plurality of network nodes.

34. The method of claim 30, further comprising:

 activating a disconnect LED of the first network node
35 if the range list is empty after deleting from the range list each network node of the one or more network nodes

which the network node has not heard from for the period of time.

35. The method of claim 30, if a parent node of the first
5 network node was not deleted from the range list and there is a vacancy in a child address list of one or more children of the first network node, further comprising:

reassigning the logical addresses of the one or more children in the child address list.

10

36. The method of claim 35, further comprising the first network node sending to the one or more children one or more corresponding reply messages informing the one or more children of the reassigned logical addresses.

15

37. A method of adding a node, having an activated proximity indicator and placed within proximate communication range of one or more of a plurality of
5 network nodes of a network, to a physical topology of the network and a logical topology representative of the physical topology, comprising:

receiving a first message containing network topology information of one or more neighboring nodes of the
10 plurality of network nodes within communication range of the node;

from the network topology information, identifying a parent node of the one or more neighboring nodes having a minimum depth from a root node of the network, wherein if
15 more than one node of the one or more neighboring nodes has the minimum depth the parent node has a minimum load of the one or more neighboring nodes; and

updating a range list of the node to include the identified parent node.
20

38. The method of claim 37, further comprising:

transmitting a second message identifying the parent node.

25 39. The method of 37, wherein prior to receiving the first message, further comprising:

the node sending a message to inform the one or more neighboring nodes of the presence of the node in the network.
30

40. A method of expanding a logical topology representative of a network having a plurality of network nodes to include a node added to the network, comprising:
- 5 transmitting a hello message to a plurality of neighboring nodes of the plurality of network nodes that are within communication range of the node;
- receiving a plurality of reply messages from the plurality of neighboring nodes containing network topology
- 10 information about the plurality of neighboring nodes; and
- updating a range list of the node to include the network topology information about the plurality of neighboring nodes.
- 15 41. The method of claim 40, further comprising:
- transmitting a broadcast confirmation message confirming that the network topology information about the plurality of neighboring nodes has been updated in the range list of the node.
- 20

42. A node operable to be placed within proximate communication range of a network node of a plurality of network nodes of a network and added to a physical topology and a logical topology of the network, comprising:

- a receiver of the node operable to receive a first message from the network node containing network topology information of the network node; and
- a processing element of the node, coupled to the receiver, operable to identify a parent node of the plurality of network nodes having a minimum depth from a root node of the network and within communication range of the node and operable to update a range list of the node to include the parent node and the network topology information of the network node.

43. The node of claim 42, further comprising:

- a transmitter of the node, coupled to the processing element, operable to transmit a second message identifying the parent node.

44. The node of 43, wherein prior to the receiver receiving the first message, the transmitter sends a message to inform one or more neighboring nodes of the plurality of network nodes within communication range of the node of the presence of the node in the network.

45. The node of claim 42, further comprising:

- a proximity indicator coupled to the processing element of the node operable to indicate when the node is within communication range of a network node.

46. A method of maintaining a physical topology of a network, having a plurality of network nodes, and a logical topology representative of the physical topology,
5 comprising:

in response to receiving a hello message from a new node wishing to join the network, a network node of the plurality of network nodes transmitting a reply message to the new node;
10 in response to the network node receiving a broadcast confirmation message from the new node, the network node adding the new node to a range list of the network node.

47. The method of claim 46, wherein in response to the
15 network node receiving the broadcast confirmation message from the new node, further comprising:
updating a child list of the range list.

48. A network node of a plurality of network nodes of a network, comprising:

5 a receiver of the network node operable to receive
from a second network node of the plurality of network
nodes within communication range of the node a incoming
message containing network topology information of the
second network node; and

10 a processing element of the network node, coupled to
the receiver, operable to update a range list of the
network node to include the network topology information
of the second network node, determine a parent node of the
network node having a minimum depth from a root node of
15 the network, and generate one or more out-going messages
containing network topology information of the network
node.

49. The network node of claim 48, further comprising:

20 a transmitter of the network node, coupled to the
processing element, operable to transmit the one or more
out-going message to the plurality of network nodes of the
network.

50. The network node of claim 48, further comprising:

25 a proximity indicator, coupled to the processing
element of the network node, operable to indicate when the
network node is within communication range of the
plurality of network nodes.

51. A method of maintaining a physical topology of a network, having a plurality of network nodes, and a logical topology representative of the physical topology, comprising:

5 a first network node of the plurality of network nodes receiving an update message containing network topology information of a second network node of the plurality of network nodes within communication range of
10 the first network node;

adding the network topology information of the second network node to a range list if the network topology information is not contained within the range list;

15 if a depth of the second network node is different from the stored value in the first network node's range list, the depth value of the second network node in the first network node's range list is updated; further comprising:

20 re-computing the minimum depth of the first network node, taken into account the new depth value of the second network node, to create a new minimum depth of the first network node;

25 if the new minimum depth is less than the original minimum depth, selecting the second network node as a parent of the first network node and updating network topology information of the first network node;

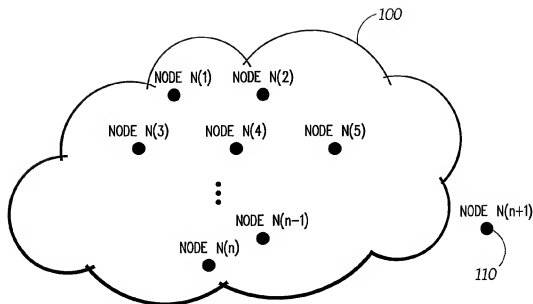
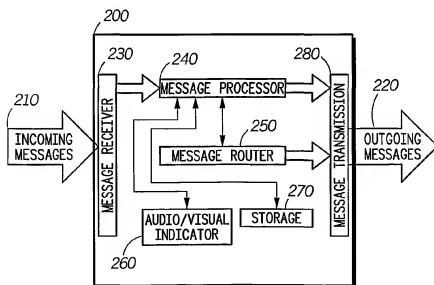
30 if the new minimum depth of the first node is greater than its original minimum depth, entering a recovery mode, wherein the recovery mode further comprises:

if an attempt to identify a third network node having a minimum depth to a root node of the network is successful, assigning the third network node as the parent of the first network node and updating network topology
35 information of the second network node; and

if the third network node cannot be identified, activating a failure indicator of the first network node.

52. The method of claim 51, further comprising:
if the first network node has not received the update message from the second network node within a predetermined period of time, comprising:
- 5 deleting the network topology information of the second network node from the range list;
determining whether the second network node was the parent of the first network node; and
- 10 if the second network node was the parent of the first network node, selecting a new parent of the first network node having a minimal depth to the root node, from the plurality of network nodes.
- 15 53. The method of claim 51, wherein the network topology information comprises depth, loading, and identifier information.

1/12

*FIG. 1**FIG. 2*

2/12

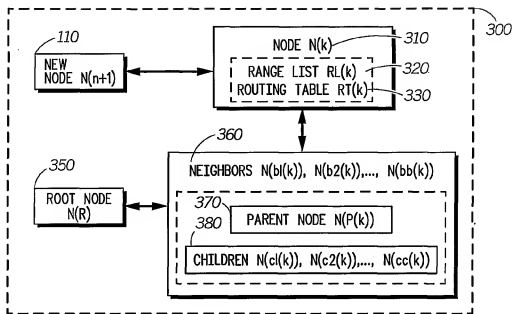


FIG. 3

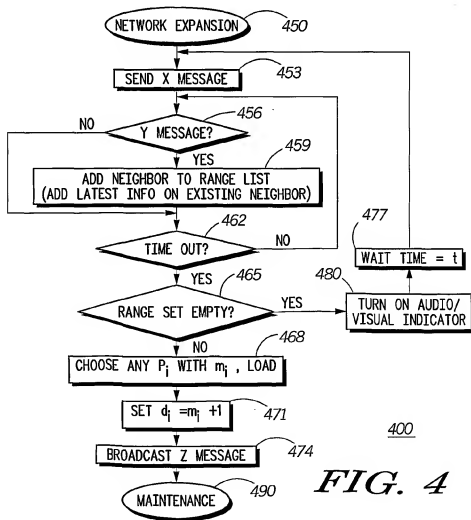
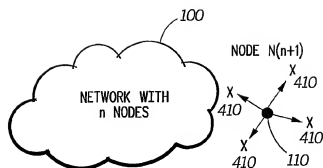
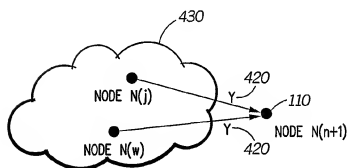
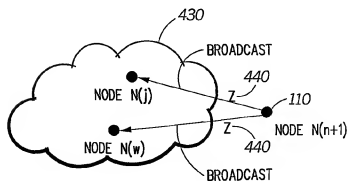
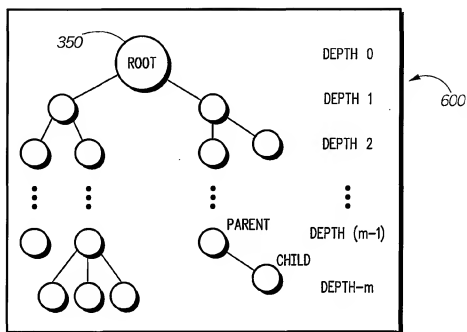


FIG. 4

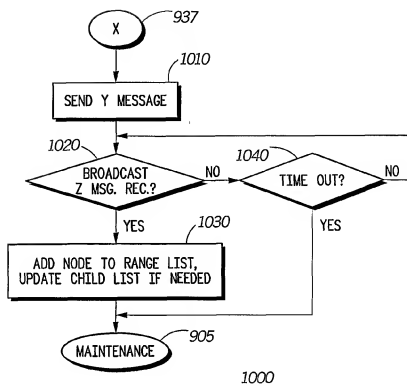
3/12

**FIG. 5****FIG. 6****FIG. 7**

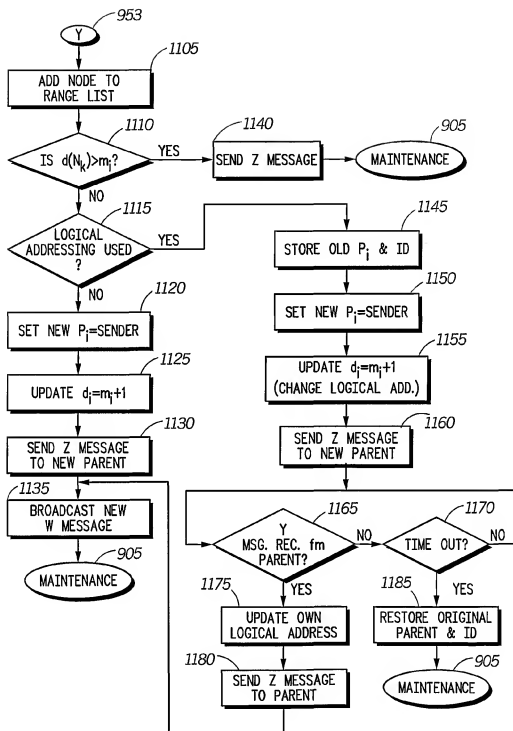
4/12

*FIG. 8*

6/12

*FIG. 10*

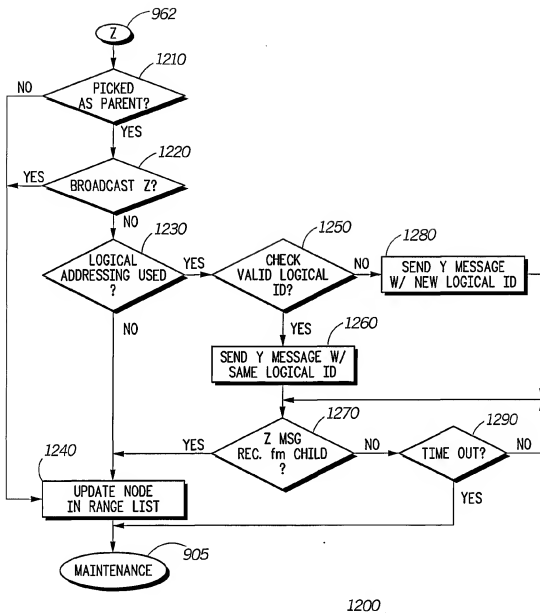
7/12



1100

FIG. 11

8/12

**FIG. 12**

9/12

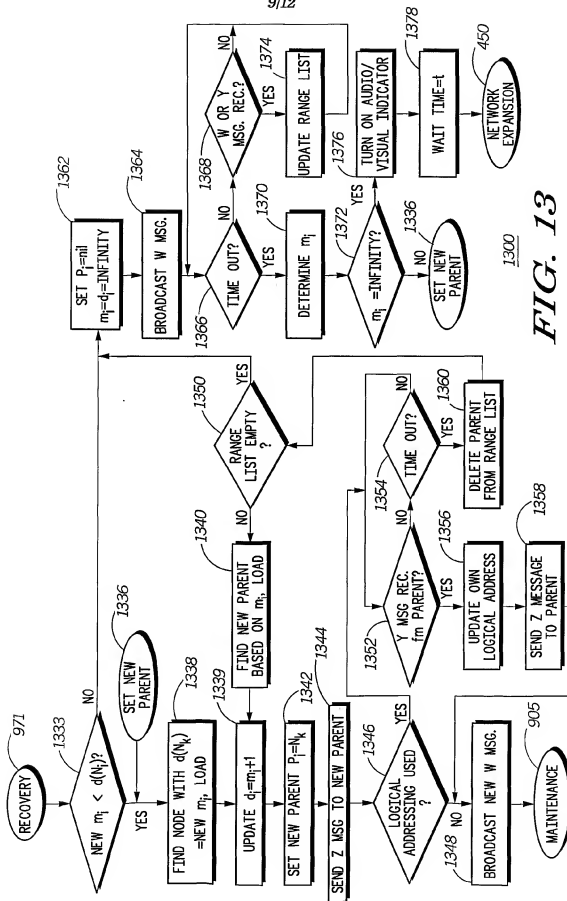
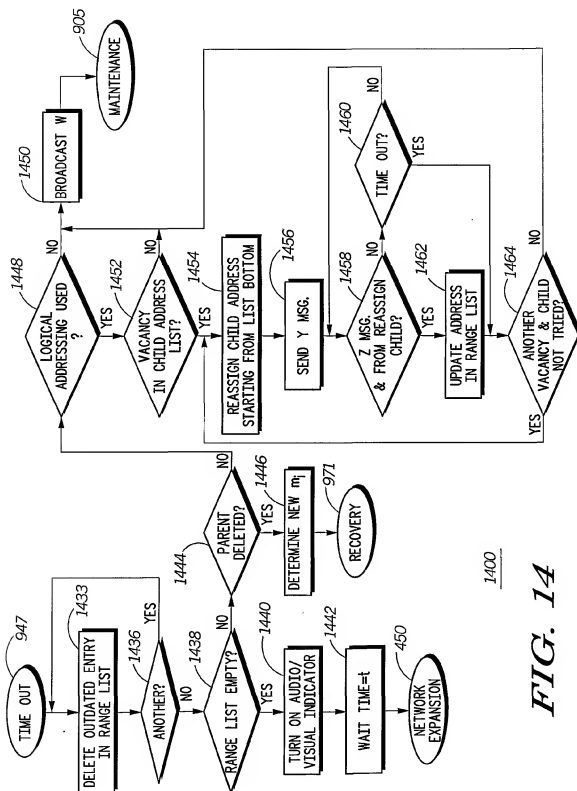


FIG. 13

10/12



1400

FIG. 14

11/12

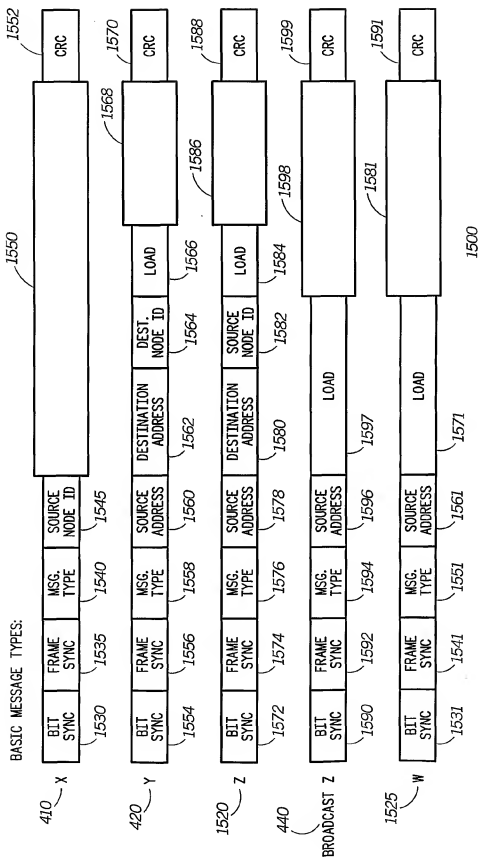
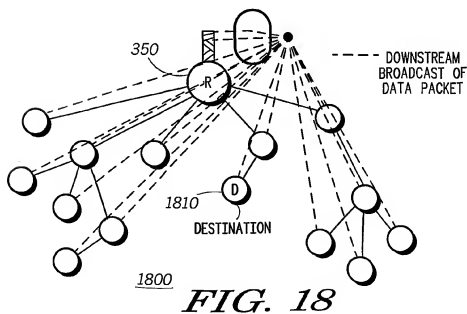
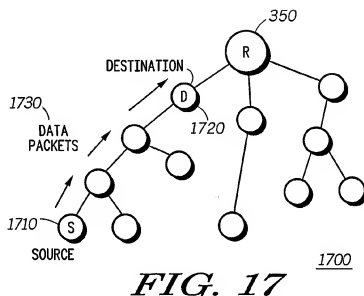
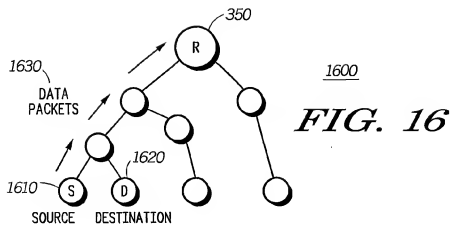


FIG. 15

12/12



INTERNATIONAL SEARCH REPORT

International application No.

PCT/US02/07217

A. CLASSIFICATION OF SUBJECT MATTER		
IPC(7) : H04L 12/28 US CL : 370/256		
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols) U.S. : 370/256, 401, 406, 408		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X, P --- Y, P	US 6,330,229 B1 (JAIN et al.) 11 December 2001 (11.12.2001), figures 1, 2, 4, 5, 7, 8, and 10; column 17, lines 6-35; column 19, lines 23-50	1, 3, 7-11, 13, 18-37, 39-43, 45-50 ----- 4-6, 12, 14-16, 44, 51-53
Y	US 6,246,689 B1 (SHAVITT) 12 June 2001 (12.06.2001), column 5, lines 35-45; column 6, lines 1-6	4-6, 12, 14-16, 44, 51-53
A	US 5,687,167 A (BERTIN et al.) 11 November 1997 (11.11.1997), column 21, lines 62-67; column 22, lines 1-33	
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "B" earlier application or patent published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" documents of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the documents are taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 12 May 2002 (12.05.2002)		Date of mailing of the international search report 15 JUN 2002
Name and mailing address of the ISA/US Communications of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703)305-3230		Authorized officer Hassan Kizou Telephone No. 703/306-0377 <i>Ronald Ward</i>

Form PCT/ISA/210 (second sheet) (July 1998)